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(19)

(54) A METHOD OF AUTOMATICALLY ORIENTING AND CONTROLLING A VEHICLE

(71) We, ITO-PATENT AG, a Company organised and existing under the laws of Switzerland, of Stampfenbachstrasse 111, Zurich, Switzerland, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method of automatically orienting and controlling a vehicle in a space for performing work on a surface in the space, over which surface the vehicle moves.

Such a method is known by which the vehicle is caused to move over the surface in a preselected sequence of paths according to a preselected programme.

An object of this invention is to provide a method by which a positioning, movement and working plan is produced by the vehicle itself.

According to this invention there is provided a method of automatically orienting and controlling a vehicle in a space for performing work on a surface in the space, over which surface the vehicle moves, in which the vehicle includes means which operate to measure scalar values from the vehicle, which values define the surface and space; supplying the scalar values to data processing means within the vehicle, the data processing means operating to produce characteristic data which geometrically defines the surface and space; processing the characteristic data within the vehicle with the aid of stored travel plan criteria to produce operating instructions for the vehicle; and supplying the operating instructions to control means within the vehicle which is thereby caused to move over the surface and perform work thereon in an optimum manner.

Scalar values for long distances can be measured by electro-optical means, while for short distances measurement can be carried out electro-optically, electro-acoustically, electrically, or magnetically. Contact between the vehicle and an obstruction can be determined either mechanically and/or electrically.

The invention will now be described by way of example with reference to the drawings, in which:

Figure 1 a block diagram showing components of a vehicle for carrying out the method of the invention;

Figure 2 illustrates operation of the vehicle;

Figure 3 illustrates operation of the vehicle's measuring means at close range;

Figure 4 illustrates operation of the vehicle's measuring means by contact;

Figure 5 illustrates position calculations carried out by the vehicle;

Figure 6 illustrates a complete movement of the vehicle over a surface;

Figure 7 is a cross section through a double wheel arrangement suitable for the vehicle;

Figure 8 is a cross section through a single offset drive suitable for the vehicle;

Figure 9 is a plan view of electro-optical apparatus suitable for use in the vehicle;

Figure 10 shows a lens system for the apparatus of Figure 9;

Figure 11 is a plan view of an electro-optical apparatus using rotating discs and with an electro-acoustic apparatus shown, suitable for use in the vehicle; and

Figure 12 is a side view of the apparatus of Figure 9 showing the position of an electro-optical surface level pick-up.

In the following description the vehicle described can be one which carries out such functions as brushing, vacuum cleaning, or grass cutting.

Referring to Figure 1, the vehicle carries:

a) An apparatus E1 with distance measuring, data collection and interface units, followed by a co-ordinate computer E2 which cooperates with a co-ordinate store E3 and an arithmetic unit E4.

b) A computer E5 interacting with the apparatus (a), and followed by a vehicle movement control unit E6 and a vehicle working control unit E7.

c) Moving means E8 for moving the vehicle and comprising drive means and position indicators serving to supply control, wheel angle data to the computer E5.

d) A monitoring apparatus E9 for continuous monitoring of the operating state of the vehicle, and causing the vehicle to react in response to the monitoring result.

e) Batteries and working apparatus such as a brushing and vacuum cleaning means, or grass cutting means, with appropriate accessories and fittings.

Each side of the vehicle is fitted with one or more electro-optical measuring devices in one or more planes at fixed angular positions (ψ) with respect to the axis of the vehicle. These provide a view of obstacles and space boundaries in all directions, and provide the basic conditions for plotting the space on a coordinate basis.

The central points of the lenses of the measuring devices have the same coordinates for input and output, and a false-light screen is associated with the lenses in order to avoid measurement errors due to obliquely received light.

The inputs and outputs of the electro-optical measuring devices are positioned on one or more rotating discs, the inputs and outputs being offset at certain angles in themselves (α) and in relation to one another (β), so that characteristic spatial points can be referred to as a guide.

Electro-acoustic sensors are positioned around the vehicle in such a way that in one or more planes for short distances tney cover the entire coordinate field to be covered. This provides a means, if required, of avoiding collisions.

Electro-acoustic transmitters and receivers are positioned on the vehicle at its edges and near the floor, preferably at the four corners near floor level, these being designed on the "system-redundant" principle, and serving to prevent depressions from having any effect on the vehicle.

In the vehicle 10 the functions of propulsion and steering are combined in each of a plurality of single units.

In one example 21 (Figure 7) two wheels 23, 24 are provided each with independent direct drive by means, for example, of a digitally actuated step motor in each unit. A shaft 25 for the wheels 23, 24, is mounted on the housing 26 of the vehicle, and is rotatable about a shaft 27 which can be locked in any angular position by means 28. The advantage of this arrangement is that both propulsion and steering of the vehicle are effected exclusively by control of the motors of the wheels 23, 24, in such a way that for travel straight ahead the motors of the wheels 23, 24 are driven synchronously. For travel round bends the wheels 23, 24 are driven at different speeds, or in different directions of rotation.

In another example 22 (Figure 8) each unit has only a single wheel 29 which is mounted at one side, and which is rotatable for steering the vehicle, by means of vertical shaft 27 mounted in the housing 26, and locable in any angular position by means 28. Propulsion and steering are here again effected solely by control of the motors, which in both examples at the same time constitute the wheels 23, 24, 29.

Power is supplied to the motors from a power unit E7 (Figure 1). The vehicle 10 carries a computer E5 (Figure 1) in which is stored a fixed travel and operating plan for the vehicle. An example of such a plan is shown in Figure 6, the object being to enable an unevenly shaped space 40, with a number of obstacles 41 to 44, to be covered in the minimum distances and time. At certain points 1 to 9*a*, shown by numbered boxes, decisions additional to the fixed plan have to be taken regarding the direction of travel. The following are among the criteria on which the travel plan can be based.

(1) Corners: Priority: rectangular corners.
Priority: those at which the longest straight lines observed intersect.
Result: travel to decision point 2 (Figure 6).
Direction of travel: in the direction of the straight line therefrom found to be the longest.
(2) Surfaces:
2.1 surfaces unbounded on both sides (see decision point 3 at 41, 6 at 42 and 8 at 43).
2.2 surface bounded at left-hand side as viewed in direction of travel (see decision point 4).
2.3 surface bounded at right-hand side as viewed in direction of travel (see decision point 7).
(3) Overlaps: to be reduced to a minimum (see decision points 4 and 9).
(4) Offset paths: (see decision point 7).
(5) Paths oblique to axis of coordinates:
5.1 beginning: travel parallel.
5.2 End.
(6) Shortest distance to boundaries: (see decision points 4 and 5).
(7) Scraping: to be avoided (see decision points 3 and 6).
(8) Change of direction.
(9) Decisions from optimization models.

Taking these preset criteria into account, the space will now be covered by the vehicle by movement thereof in parallel paths.

The computer E5 receives information from a positioning store concerning the shape of the space 40 including any objects 41, 43, present therein. In contrast to known methods

this information is not stored in the form of a true-to-scale plan model, but is determined by determination of coordinates characterising the space and contents (see Figure 6, e.g. 1, 1—2, 2—3, 3—4 etc), related to a self-obtained (i.e. by the vehicle) and selected fixed reference point of the space or surface, as the origin of the coordinates by means of a coordinate computer E2. The necessary content of the store is thus considerably reduced by comparison with that involved when the space is represented as a model in the store. The position of the vehicle is retained, for example, by placing a current coordinate (see f′ (x′, y′z′, b, t) in Figure 1 (E5, E3)) in the store, and characteristic coordinates (see f (x, y, z, b)) in Figure 1 (E3 and E5) can then at the same time be likewise indicated for this purpose. Both the characteristic f (x, y, z, b) and the running coordinates f′ (x′, y′, z′, b, t) are the result of a reduction, verification and correlation of the continuously entering input information by an overriding permanently wired arithmetic unit E4. The purpose of this arithmetic unit is on the one hand to provide an overall view of the space by means of the coordinates f (x, y, z, b) and on the other hand to effect a continuous verification thereof and thus provide a guarantee of their correctness and freedom from contradiction. Using the overriding orientation strategy it is able to "intervene" in the fixed plan in the computer E5 and must, if necessary "inform" the coordinate computer E2 of a new or corrected coordinate reference point.

In the computer E2, the conversion of the scalar values (see s_1 s_8 in Figure 2) coming from the measuring means E1 into space- or surface-based coordinates f (x, y, z, b) and f′ (x′, y′, z′, b, t) is effected by known mathematical laws, as shown in Figure 5.

From the arithmetic unit E4 is obtained the additional information on the operating state (see f (. . .) in Figure 1), for the designation of the relevant coordinates f (x, y, z, b) and f′ (x′, y′, z′, b, t).

The measuring means E1 performs direct measurement of the scalar values e.g. s_1—s_8 in Figure 2, not only for long distances (see Figure 2) but also at short distances (Figure 3) and even with contact (Figure 4). The basic part of this measuring means E1 is an electro-optical distance measuring means shown in Figures 2, 5 and 6 which supplies very accurate measured values. As shown in Figures 2, 5 and 6, this is done by providing on each side of the vehicle 10 inputs and outputs 11 and 12 (see Figure 9) of a measurmeans 13. By the eight scalar values s_1 to s_8 received (shown in Figure 2) and which owing to the constructional arrangement on the apparatus (see Figures 11 and 12) are fixed in their directions (see Figure 11), characteristic surface or space boundaries or corner points (e.g. 1, 1—2, 2—3 etc., see Figure 6) are calculated as may be seen from Figure 5 which shows the transformation of the coordinates, which is carried out by the computer E2, x_1 and y_1 are the coordinates of corner point 50 determined from the scalar distances s_1—s_4 (position of apparatus 51), this corner point 50 thus being usable, in turn, as a hypothetical coordinate reference point.

The correlation of the results of the distance measuring units 17 for short distances (see Figures 3 and 11), which may be of the electro-acoustic type, and of the electro-mechanical or electrical measuring units 60 for contact (see Figure 4), is carried out in the arithmetic unit E4.

In the apparatus E9 the operational efficiency and the operating state, particularly the power supply, of the vehicle 10, are continuously monitored, and appropriate measures such as for servicing, automatic charging, refilling etc., are provided. The vehicle 10 can move automatically to a charging station for self-connection therewith.

It is in the complex interaction of measuring unit E1 with computers E2 and E5 (see Figure 1) that the basic principle of the present invention resides. It incorporates both the evalution of redundancy of the measuring units and the ability of the vehicle to find its way automatically about unknown spaces. In Figure 1 for instance, the data connection between E1 and E5 serves to inform the computer E5 of the relative angles ψ, which are determined, for example, by means of a gyro (not shown), and the relative movement paths, which are determined, for example, by a friction wheel. Via the connection with E8 the computer E5 receive an indication of the steering angle ε, that is the angular position between the wheels and the axis of the vehicle and is thus able to carry out any necessary movement path corrections.

The movement plan and the path calculation and correction are dependent upon knowledge of the area to be processed. This information is received by the vehicle 10 as a result of the cooperation between the measuring unit E1, the coordinate computer E2, the arithmetic E4 and the store E3, on the one hand, and the arithmetic E4, the store E3 and the computer E5 on the other.

Figure 6 shows how the apparatus receives characteristic coordinates. It is thus able to calculate, for example, the point 2 immediately on entering the space 40. The other characteristic coordinates, such as the corner points included in the drawing, are received during movement between the decision points 1—9a. It can be seen from Figure 6 what characteristic points it can measure or calculate on its way between 1—2, 2—3, 3—4, 4—5, 5—6, 6—7, 7—8, 8—9 and 9—9a. It is thus also possible, as a general principle, despite passages and openings 45, to treat spaces as

self-contained units. By the continual calculation of new characteristic coordinates, and the erasure of stored coordinates when moved through, the method of the invention enables the vehicle to cover a very large surface without involving the storage of more than a minimum amount of data.

Figure 10 shows how an optical lens system can be arranged for the inputs and outputs 11 and 12, of which the central points have the same coordinates.

The electro-acoustic transmitters 19 and receivers 20 installed in the outermost zones and close to the floor, preferably at the four corners 18 close to the floor, are shown in Figure 12 and are used, for example, for the protection of the apparatus when stairs are approached. Figure 12 also shows the angle of inclination δ, while Figure 11 shows the angles α and β by which the electro-optical inputs and outputs 11 and 12 are offset in relation to each other in one particular embodiment of the invention. The advantage of this version resides in the fact that it can be universally orientated in three dimensions without involving any ambiguous measuring results.

WHAT WE CLAIM IS:—

1. A method of automatically orienting and controlling a vehicle in a space for performing work on a surface in the space, over which surface the vehicle moves, in which the vehicle includes means which operate to measure scalar values from the vehicle, which values define the surface and space; supplying the scalar values to data processing means within the vehicle, the data processing means operating to produce characteristic data which geometrically defines the surface and space; processing the characteristic data within the vehicle with the aid of a stored travel plan criteria to produce operating instructions for the vehicle; and supplying the operating instructions to control means within the vehicle which is thereby caused to move over the surface and perform work thereon in an optimum manner.

2. A method in accordance with Claim 1, wherein distance measurement is carried out electro-optically for long distances.

3. A method in accordance with Claim 1 or Claim 2, wherein short distance measurement is carried out electro-optically and/or electro-acoustically and/or electrically or magnetically.

4. A method in accordance with any preceding Claim, wherein contact between the vehicle and an obstacle is determined mechanically and/or electrically.

5. A vehicle for use in a method as claimed in Claim 1, comprising an apparatus with distance measuring, data collection and interface units, and connected to a co-ordinate computer, a co-ordinate store and an arithmetic unit; a second computer connected to the co-ordinate computer, store and arithmetic unit and operating to control a vehicle movement control unit and a vehicle working control unit; and moving means for moving the vehicle, and comprising drive means and position indicators serving to supply control, wheel angle data to the second computer.

6. A vehicle as claimed in Claim 5, including monitoring apparatus for continuously monitoring the operating state of the vehicle, and causing the vehicle to react in response to the monitoring result.

7. A vehicle as claimed in Claim 5 or Claim 6, in which the drive means comprises two or more digitally controllable driving motors.

8. A vehicle as claimed in Claim 7, in which the vehicle is steered solely by the drive motors.

9. A vehicle as claimed in Claim 5, 6, 7 or 8, including on each side of the vehicle in fixed planes and angular positions with respect of the axis of the vehicle, one or more inputs and outputs of an electro-optical distance measuring system.

10. A vehicle as claimed in Claim 9, in which each input of the electro-optical distance measuring system has an associated output having the same central point.

11. A vehicle as claimed in Claim 9 or Claim 10, in which the inputs and outputs of the electro-optical distance measuring system are located on one or more rotating discs, the angles of the inputs and outputs on each disc being offset in themselves and in respect of one another.

12. A vehicle as claimed in any one of Claims 5 to 11, including electro-acoustic sensors positioned around the vehicle in such a way that in one or more planes over a short distance they sense the entire coordinate field.

13. A vehicle as claimed in any one of Claims 5 to 12, including electro-acoustic transmitters and receivers at the extremities of the vehicle and close to floor level.

14. A method of automatically orienting and controlling a vehicle, substantially as herein described with reference to the drawings.

15. A vehicle substantially as herein described with reference to the drawings.

KINGS PATENT AGENCY LIMITED,
By J. B. King, Director,
Registered Patent Agent,
146a Queen Victoria Street,
London, EC4V 5AT.
Agents for the Applicant.

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Fig. 1

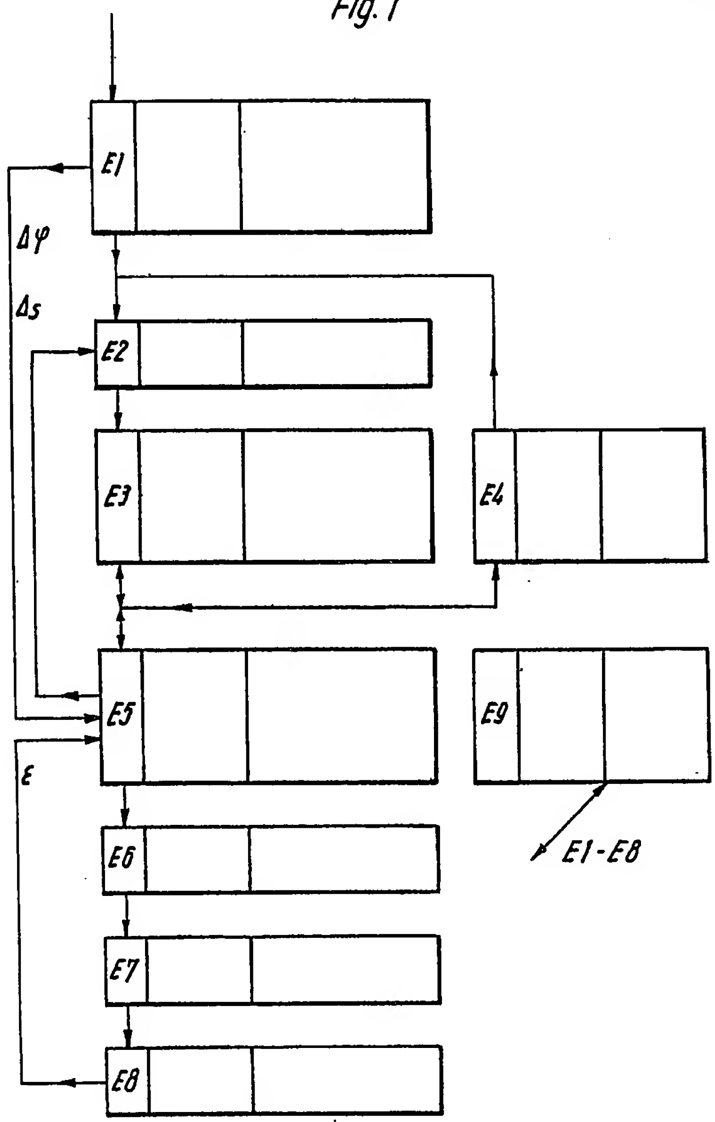


Fig.2

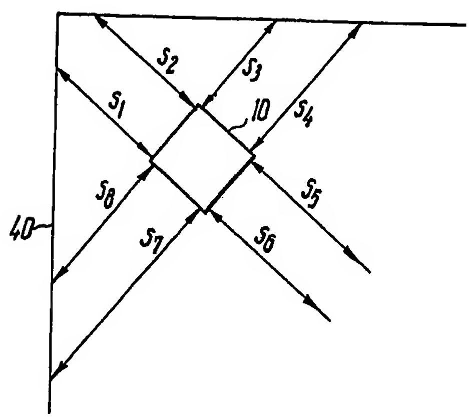


Fig.3

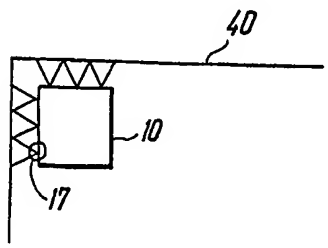
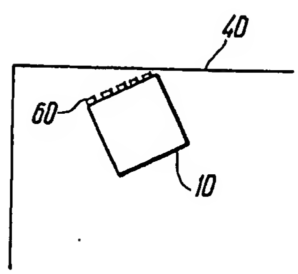


Fig.4



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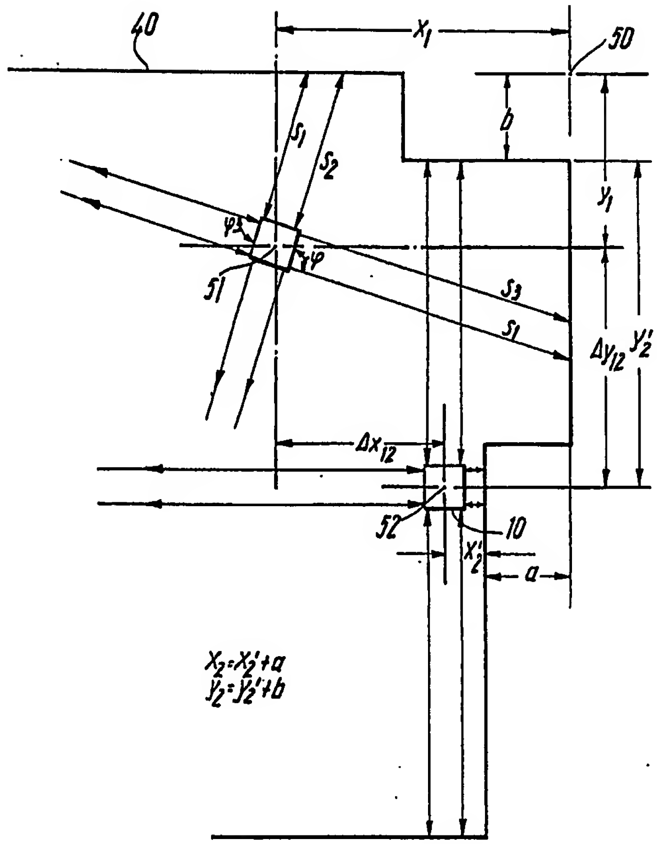
Sheet 3

Fig. 5



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Sheet 4

Fig.6

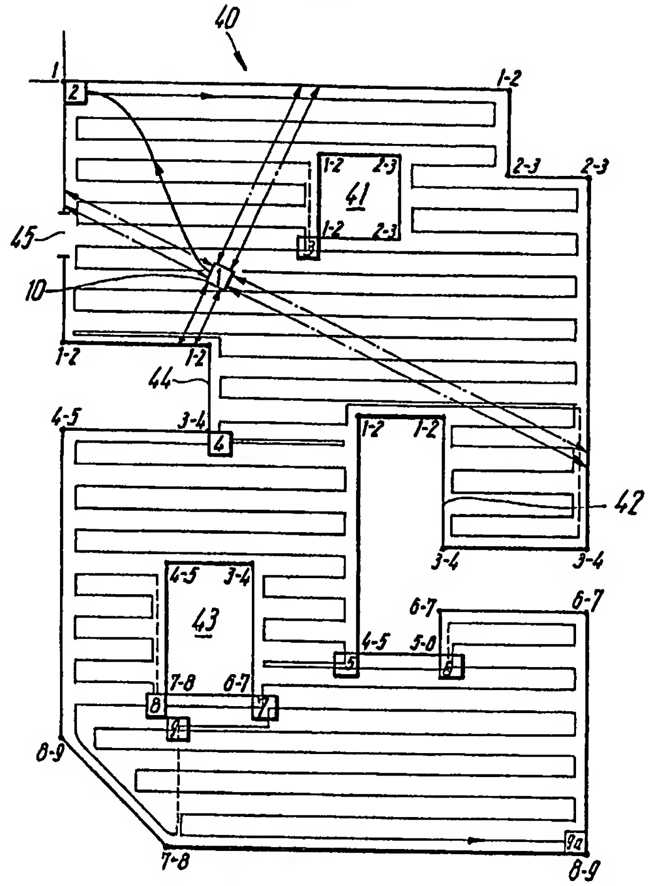

Fig.7

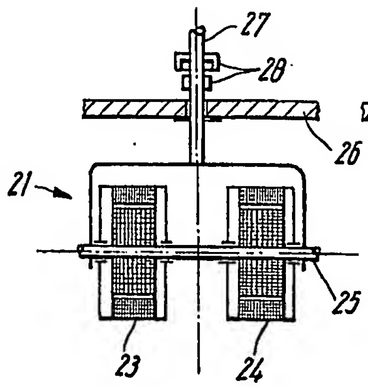

Fig.8

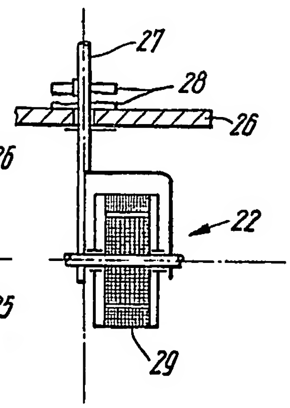

Fig.9

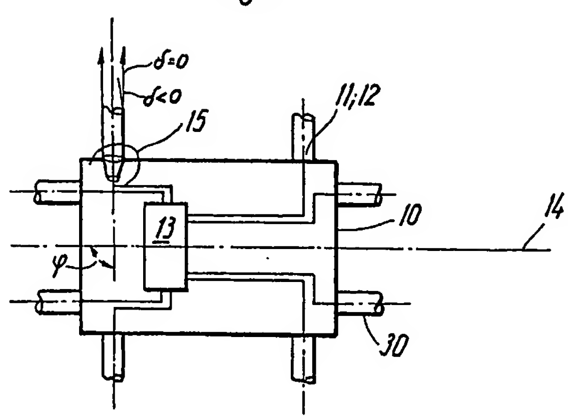

Fig. 10

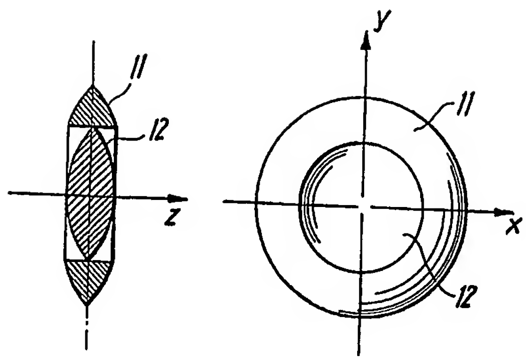

Fig. 11

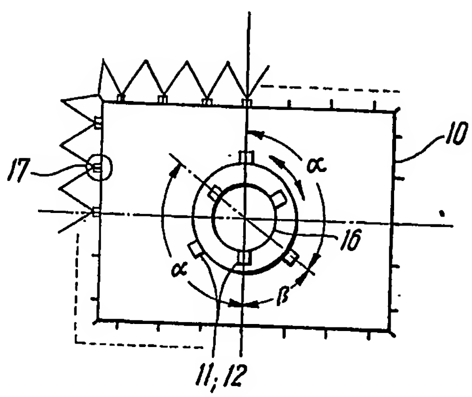

Fig.12